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INTERNAL NOTE MSC-EP-R-68-18

EVALUATION OF BROMOTRIFLUOROMETHANE  
AS A FIRE EXTINGUISHING AGENT  
FOR APOLLO HYPERGOLIC  
PROPELLANTS

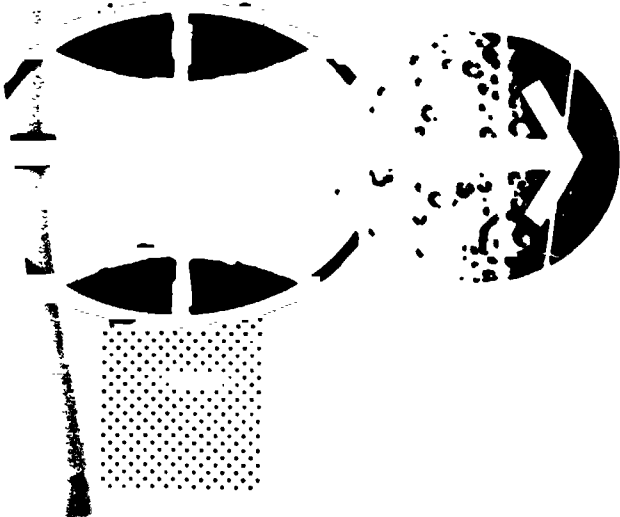


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THERMOCHEMICAL TEST BRANCH  
PROPULSION AND POWER DIVISION  
MANNED SPACECRAFT CENTER  
HOUSTON, TEXAS  
November 22, 1968

THERMOCHEMICAL TEST AREA  
PROPULSION AND POWER DIVISION  
NASA - MANNED SPACECRAFT CENTER  
HOUSTON, TEXAS

EVALUATION OF BROMOTRIFLUOROMETHANE  
AS A FIRE EXTINGUISHING AGENT  
FOR APOLLO HYPERGOLIC  
PROPELLANTS

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## ABBREVIATIONS

Btu/gal	British thermal units per gallon
cc/sec	cubic centimeters per second
cfm	cubic feet per minute
KSC	Kennedy Space Center
lb/gal	pounds per gallon
lb/sec	pounds per second
lb/min	pounds per minute
LM	lunar module
NFPA	National Fire Protection Association
ppm	parts per million
psig	pounds per square inch, gage
SLA	spacecraft/lunar module adapter
scf	standard cubic feet
scfm	standard cubic feet per minute
UDMH	unsymmetrical dimethylhydrazine

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## SYMBOLS

A-50	Aerozine-50 fuel
Br <sub>2</sub>	bromine
CO <sub>2</sub>	carbon dioxide
F <sub>2</sub>	fluorine
FE-1301	Freon fire extinguisher number 1301
GN <sub>2</sub>	gaseous nitrogen
HBr	hydrogen bromide
HF	hydrogen fluoride
N <sub>2</sub> H <sub>4</sub>	hydrazine
N <sub>2</sub> O <sub>4</sub>	nitrogen tetroxide
NO <sub>2</sub>	nitrogen dioxide

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## INTRODUCTION

The evaluation of bromotrifluoromethane (Freon FE-1301) as a fire extinguishing agent for protection of hypergolic systems which was initiated on June 5, 1968, was conducted by the Materials Laboratory, Thermochemical Test Branch, Propulsion and Power Division at the Ellington Air Force Base, building 1151.

The primary objective of this evaluation was to determine the advisability of using Freon FE-1301 for fire extinguishment in the Apollo spacecraft lunar module (LM) adapter area (SLA). Possible fires in the SLA would probably originate from leakage of hypergolic propellants on board the LM and would possibly be influenced by the large area of exposed aluminum metal surfaces through catalysis.

Because of the possibility of propellant fires occurring in the Saturn IB or Saturn V following propellant introduction into their tanks, the SLA area is provided with a Freon FE-1301 spray capability and a water-flooding capability. Launch complex 39A (Saturn V) is also being designed with both Freon FE-1301 and water-flooding capabilities in the SLA.

Work in the Structures and Mechanics Division laboratories indicates that Freon FE-1301 in pure oxygen at 5 psia in the presence of burning polyurethane foam reacts vigorously and evolves free bromine, hydrogen halides, and considerable heat. Because of this, sufficient suspicion existed to warrant further laboratory testing to ascertain the advisability of using Freon FE-1301 in the described manner to extinguish hypergolic fires.

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## BACKGROUND INFORMATION

The National Fire Protection Association (NFPA) classifies fire and explosion extinguishment as methods A, B, C, D, E, and F (ref. 1). These methods are described in the following manner:

1. Method A, extinguishment by cooling — The temperature is reduced to a point at which burnable gases are no longer produced and/or chemical reaction rates are reduced to extinction.

2. Method B, extinguishment by separation or replacement of oxidizing agent from fuel — The oxidizing agent is separated from the fuel by a blanket of inert material.

3. Method C, extinguishment by dilution or removal of fuel supply — The fuel/air ratio is reduced below the explosive mixture range by dilution with inert gas or additional air or by reducing the fuel intake.

4. Method D, chemical extinguishment — The reaction chain is broken by use of special chemicals, such as halogenated hydrocarbons or sodium bicarbonate.

5. Method E, explosion suppression — The explosion is stopped before destructive pressures are developed. The effectiveness is dependent upon the discharge of a chemical reaction chain breaking agent in the explosion zone during the first few milliseconds of the explosion.

6. Method F, explosion venting — The destructiveness of explosions is minimized by providing physical means of releasing explosion pressures from enclosures before destructive pressures are developed.

Obviously, some of the factors involved in certain methods overlap other methods. For example, the separation of oxygen from the fuel by foam in method B will tend to cool the system as specified in method A. The extinguishment by bromotrifluoromethane (Freon FE-1301) in method D is effected to a small extent by cooling. This cooling effect is relatively insignificant because the latent heat of vaporization of Freon FE-1301 is only 28 calories per gram compared to 540 calories per gram for water (ref. 2). Extinguishment by Freon FE-1301 under certain circumstances could be effected by replacement of the oxidizing agent. Dilution of the fuel could be a factor also. However, the primary mechanism of extinguishment by Freon FE-1301 is that of breaking the reaction chain by special chemicals as indicated under method D.

It is a well established fact that some unusual mechanism is responsible for the effectiveness of certain halogenated hydrocarbons and of certain inorganic salts as extinguishing agents. The fact that the percentage of methyl bromide required to extinguish a hexane fire was about one-sixth the percentage of nitrogen required was a strong indication that some factor other than cooling, smothering, or blowing out was involved. When dry chemical (sodium bicarbonate base) was first developed as an extinguishing agent, it

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was thought that carbon dioxide, released when the product was heated, was the effective agent. This theory was discarded when it was shown that dry chemical was about twice as effective as an equal amount of carbon dioxide. Further evidence against the idea that carbon dioxide was the effective agent was recognized from the fact that ammonium carbonate, which readily forms carbon dioxide when heated, is a poor extinguishing agent. Recent research has given strong support to the chemical extinguishing theory which attributes the effectiveness of halogenated hydrocarbons or inorganic salts to their reaction with intermediate products of combustion. It is theorized that this reaction breaks the combustion reaction chain and thus stops the combustion. The active part of the halogenated hydrocarbon molecule in the combustion chain breaking mechanism is the halogen atom or ion. It has also been established that the effectiveness of the halogens in decreasing order is iodine, bromine, chlorine, and fluorine, all other factors being equal (ref. 2). However, Freon FE-1301 ranks high among available extinguishing liquids because of its effectiveness as indicated in table I and because of its relatively low toxicity as indicated by tables II, III, IV, V, and VI.

The effectiveness of Freon FE-1301 in extinguishing a burning hypergolic mixture of A-50 fuel and  $N_2O_4/NO_2$  would be difficult to predict. This would be true, particularly if the mixture were a spill of undefinable quantities and conditions. There is no doubt that under certain conditions Freon FE-1301 can contribute to extinguishment by cooling, by dilution of the fuel, and by breaking the reaction chain with the end result of overwhelming the fire. On the other hand, under certain conditions in which strong oxidizing gases ( $HF$ ,  $F_2$ ,  $Br_2$ , etc.) were released, it would seem possible that Freon FE-1301 might contribute to the conflagration. In any case, it should be expected that Freon FE-1301 will not completely snuff out a fire resulting from the reaction of the two hypergolic propellants, nitrogen tetroxide and Aerozine-50. The fire, though subdued by the Freon FE-1301, will revive immediately after discontinuance of the Freon FE-1301 spray, provided both nitrogen tetroxide and Aerozine-50 remain in contact with each other.

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### TEST EQUIPMENT

The test program was carried out inside a closed aluminum cabinet (4 by 4 by 4 feet) shown in figures 1, 2, 3, and 4 and equipped with the following:

1. An aluminum alloy AA-2024 reaction tray
2. An A-50 inlet system with remote-controlled flow to the reaction tray
3. A nitrogen tetroxide inlet system with remote-controlled flow to the reaction tray
4. A freon spray system with remote-controlled flow to four nozzles
5. A water spray system with remote-controlled flow to eight nozzles
6. A gaseous nitrogen flow system with remote-controlled flow to four nozzles
7. A copper-constantan thermocouple located above the reaction tray and connected to a high-speed recorder
8. A hot-wire igniter suspended from the top of the cabinet and extending to the reaction tray
9. Flap vents at the bottom to avoid pressure build-up in the cabinet
10. Plexiglass windows for viewing and photographing the reactions
11. Vapor sampling nozzles connected to evacuated gas sample cylinders
12. A remote-controlled motion picture camera located at the back window
13. A remote-controlled closed-circuit television system with the camera located at the back window

The tests were controlled and data were recorded electronically through a console which was isolated from the test area by a concrete wall. This console, including the closed-circuit television monitor, is shown in figure 5.

Aluminum alloy AA-2024 (commonly known as alloy 2024) was selected for the reaction tray because the SLA housing on which A-50 and/or  $N_2O_4$  might leak is constructed of this alloy. It was suspected that the aluminum alloy, by catalysis, might influence the reaction.

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### TEST MATERIALS DESCRIPTION

The various materials used in the test are listed and described as follows:

1. FE-1301 — Freon FE-1301 is manufactured and supplied by E. I. DuPont de Nemours and Company, Incorporated. It has the following properties (ref. 3):

- a. Chemical name, bromotrifluoromethane
- b. Boiling point at atmospheric pressure,  $-72^{\circ}$  F
- c. Freezing point,  $-270.4^{\circ}$  F
- d. Liquid density at  $70^{\circ}$  F, 13.1 lb/gal
- e. Heat of vaporization, 47.7 Btu/lb

2. Aerozine-50 — A-50 is a blend of 48.2-percent-weight unsymmetrical dimethylhydrazine (UDMH) and 51.0-percent-weight hydrazine with 0.8-percent-weight water.

3. Nitrogen tetroxide ( $N_2O_4$ ) — Nitrogen tetroxide has the chemical formula  $N_2O_4$ . In the liquid state under pressure,  $N_2O_4$ , which is in equilibrium with  $NO_2$ , is predominantly  $N_2O_4$ . The opposite is true in the gaseous state. A mixture of A-50 and  $N_2O_4$  is hypergolic.

4. Polyurethane foam — The polyurethane foam was in the form of blocks, 1 by 4 by 6 inches. The number of holes in the foam structure was in the order of 100 000 per cubic inch.

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**TEST PROGRAM**

The test program was designed with the following objectives:

1. To determine if liquid Freon FE-1301 will extinguish the hypergolic reaction between liquid A-50 and liquid  $N_2O_4$
2. To determine if an atmosphere of Freon FE-1301 (with little or no liquid present) will diminish the flame produced by the hypergolic reaction of A-50 and  $N_2O_4$
3. To determine if liquid Freon FE-1301 will extinguish a burning pad of polyurethane foam which is saturated with  $N_2O_4$  and is lying on an aluminum alloy AA-2024 plate
4. To determine if gaseous nitrogen will extinguish a burning pad of polyurethane foam which is saturated with  $N_2O_4$  and is lying on an aluminum alloy AA-2024 plate
5. To determine if gaseous nitrogen will extinguish the hypergolic reaction between liquid A-50 and liquid  $N_2O_4$
6. To determine if ammonia, free halogens, or hydrogen halides are formed from any of the reactions taking place while the hypergolic flame from propellants is sprayed by Freon FE-1301 or by gaseous nitrogen
7. To investigate chemical reactions or catalytic effect between liquid Freon FE-1301 in air at ambient conditions with aluminum alloy AA-2024 plate
8. To determine if liquid Freon FE-1301 and liquid A-50 fuel will chemically react in air at ambient conditions when exposed to aluminum alloy AA-2024 plate
9. To determine if liquid Freon FE-1301 and liquid  $N_2O_4$  will ignite spontaneously in air or show other chemical reactions when exposed to aluminum alloy AA-2024 plate in air under ambient conditions

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## TEST PROCEDURE

Before any testing was started the flow rates of liquid nitrogen tetroxide, liquid A-50, liquid Freon FE-1301, gaseous nitrogen, and water were established as follows:

1. Nitrogen tetroxide, 0.3 lb/sec
2. A-50 fluid, 0.2 lb/sec
3. Freon FE-1301 (spray), 20.0 lb/min
4. Gaseous nitrogen, 14 cfm
5. Water (spray) 1/2-inch line, full flow

Immediately before and after each test, the reaction cabinet and reaction tray were washed with water and dried.

Each test schedule was carried out by manual operation of the control console while time was observed on a stop watch. The results were observed on the closed-circuit television, recorded on color film, and recorded by the control console. The temperature above the reaction tray was recorded on a high-speed strip recorder.

All tests were started under ambient conditions and the vents at the bottom of the cabinet precluded pressure buildup during the test.

The following is a typical stepwise schedule used in this program:

<u>Elapsed time, sec</u>	<u>Action</u>
0	A-50 on
10	N <sub>2</sub> O <sub>4</sub> on, camera on
22	Freon on
44	Freon off
57	A-50 off, N <sub>2</sub> O <sub>4</sub> off
60	Freon on
84	Freon off, camera off

## RESULTS AND DISCUSSION

The results of 11 combustion and extinguishment tests are shown in table VII. None of the data shows a deviation from the expected.

Test number 1 shows that Freon FE-1301 is not significantly affected by aluminum alloy AA2024 at ambient conditions.

Tests 2 and 3 show no significant reaction of Freon FE-1301 with either nitrogen tetroxide or A-50 fuel at ambient conditions.

Test 4 is the control test for the test conditions and shows the normal hypergolic reaction for nitrogen tetroxide and A-50 fuel.

Tests 5 and 6 show that the hypergolic fuel, nitrogen tetroxide and A-50, is extinguished by Freon FE-1301, but is not extinguished by gaseous nitrogen.

Tests 7 and 8 show that polyurethane sponge saturated with nitrogen tetroxide is not hypergolic, but can be easily ignited by a hot wire. Test 8 shows that the flaming polyurethane saturated with nitrogen tetroxide is easily extinguished by Freon FE-1301. Test 9 shows that this system is not extinguished by gaseous nitrogen.

Test 10 is shown in progress, pictorially, by figures 6 and 7. Figure 6 shows polyurethane saturated with A-50 fluid being sprayed with Freon FE-1301. Figure 7 shows the flame produced by the addition of nitrogen tetroxide with continuous Freon FE-1301 spray.

Test 11 is shown in progress, pictorially, by figures 8, 9, 10, and 11. Figure 8 shows the flame produced by A-50 fuel and nitrogen tetroxide. Figure 9 shows the flame still burning after approximately 10 seconds of continuous Freon FE-1301 spray. Figure 10 shows no visible flame after 22 seconds additional Freon FE-1301 spray and figure 11 shows the flame immediately after the Freon FE-1301 spray was discontinued. There is no certainty that the flame was extinguished when the picture in figure 10 was taken because vision was obscured by the Freon FE-1301 fog. However, it is reasonable to assume that the excess amounts of Freon FE-1301 present at this point could and did extinguish the flame temporarily.

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**CONCLUSIONS**

1. The flame from a mixture of A-50 fuel and  $N_2O_4$  can be reduced and probably extinguished momentarily, or so long as copious quantities of liquid Freon FE-1301 are used. However, any lingering A-50 fuel and  $N_2O_4$  mixture will reignite when the flow of Freon FE-1301 is stopped.
2. Polyurethane sponge and  $N_2O_4$ , though not hypergolic, will flame in air when ignited by an outside source. This flame can be extinguished by Freon FE-1301.
3. The flame from burning polyurethane saturated with  $N_2O_4$  cannot be extinguished by an atmosphere of gaseous nitrogen.
4. The flame from a mixture of A-50 fuel and  $N_2O_4$ , with or without polyurethane sponge, cannot be extinguished by an atmosphere of gaseous nitrogen.
5. Only under optimum conditions will a flame resulting from spontaneous ignition of polyurethane saturated with A-50 in the presence of excess  $N_2O_4$  be extinguished, even momentarily, by Freon-1301.
6. Liquid Freon FE-1301 does not ignite spontaneously in air at ambient conditions with aluminum alloy AA-2024 plate as a catalyst.
7. Liquid Freon FE-1301 and liquid A-50 fuel do not ignite spontaneously in air at ambient conditions with aluminum alloy AA-2024 plate as a catalyst.
8. Liquid Freon FE-1301 and liquid  $N_2O_4$  or the vapors of these compounds do not ignite spontaneously in air at ambient conditions with aluminum alloy AA-2024 plate as a catalyst.
9. Polyurethane sponge and A-50 fuel do not ignite spontaneously in air at ambient conditions with aluminum alloy AA-2024 plate as a catalyst.
10. Polyurethane sponge and  $N_2O_4$  do not ignite spontaneously in air at ambient conditions with aluminum alloy AA-2024 plate as a catalyst.

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### REFERENCES

1. NFPA Fire Protection Handbook, Twelfth Edition, Section 4.
2. NFPA Fire Protection Handbook, Twelfth Edition, Section 15.
3. E. I. DuPont de Nemours and Company, Bulletin B-29.

TABLE I.- WEIGHT EFFECTIVENESS, IN PERCENTAGE, OF SELECTED  
EXTINGUISHING AGENTS AGAINST CLASS B AND COTTON WASTE FIRES<sup>a</sup>

[Average of 10 tests unless otherwise noted; research by  
Engineer Research and Development Laboratories]

Agent and formula	Halon no.	Class B 24-inch tub fire, agent at 800-psig initial discharge pressure (b)			Class B 24-inch tub fire, agent at 400-psig initial discharge pressure (b)			Two- by 4-foot cotton waste fire, agent at 400-psig initial discharge pressure (b)		
		To extinguish		Weight effectiveness, percent (c)	To extinguish		Weight effectiveness, percent (c)	To extinguish		Weight effectiveness, percent (c)
		Average weight agent, oz	Average time, sec		Average weight agent, oz	Average time, sec		Average weight agent, oz	Average time, sec	
Dibromodifluoromethane, CBr <sub>2</sub> F <sub>2</sub>	1202	7.6	1.9	148	6.6	1.4	170	20	5.7	100
Bromotrifluoromethane, CBrF <sub>3</sub>	1301	7.7	3	146	<sup>d</sup> 7.6	<sup>d</sup> 3	<sup>d</sup> 105	15.6	6.7	126
Carbon dioxide, CO <sub>2</sub>	--	9.1	5.2	124	9.1	5.2	88	<sup>h</sup> 32	--	--
Dibromotetrafluoroethane, CBrF <sub>2</sub> CF <sub>2</sub>	2402	10.5	2	107	10.8	2.3	74	<sup>h</sup> 19.8	--	--
Dichlorodifluoromethane, CCl <sub>2</sub> F <sub>2</sub>	122	10.8	3	104	12	4.1	68	<sup>g</sup> (27)	<sup>g</sup> (10)	<sup>g</sup> (74)
Methyl bromide, CH <sub>3</sub> Br	1001	11.3	3.4	100	8.0	2.1	100	20	5	100
Ethyl bromide, CH <sub>3</sub> Br	2001	11.7	2.8	96	<sup>e</sup> (16)	<sup>e</sup> (5.5)	<sup>e</sup> (50)	--	--	--
Methyl iodide, CH <sub>3</sub> I	10001	11.7	2.8	96	--	--	--	--	--	--
Chlorobromomethane, CH <sub>2</sub> BrCl	1011	12.7	2.7	80	--	--	--	--	--	--
Carbon tetrachloride, CCl <sub>4</sub>	104	<sup>e</sup> (15)	<sup>e</sup> (3)	<sup>e</sup> (75)	11.4	2.0	68	<sup>h</sup> 32	--	--
Perfluoromethylcyclohexane, C <sub>6</sub> F <sub>11</sub> CF <sub>3</sub>	--	--	--	--	<sup>f</sup> (24)	<sup>d</sup> (7)	<sup>f</sup> (33)	<sup>h</sup> 32	--	--
Bromochlorodifluoromethane, CBrClF <sub>2</sub>	1211	--	--	--	10.7	2.3	75	--	--	--
1, 2-dibromo-1, 1-difluoroethane, CF <sub>2</sub> BrCH <sub>2</sub> Br	2202	--	--	--	12	2.2	66	--	--	--

<sup>a</sup>See reference 2.

<sup>b</sup>Agents were discharged from a 2-1/2-pound CO<sub>2</sub> extinguisher charged with 2 pounds of agent, and then pressurized with nitrogen at 70° F. CO<sub>2</sub> discharge pressure in all cases was approximately 800 psig.

<sup>c</sup>Methyl bromide taken as 100 percent.

<sup>d</sup>Five tests.

<sup>e</sup>Average values for successful extinguishments only (six failures in 10 tests).

<sup>f</sup>See (e), three failures in five tests.

<sup>g</sup>See (e), two failures in five tests.

<sup>h</sup>Not effective in combating the fires.

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TABLE II.- APPROXIMATE LETHAL CONCENTRATIONS FOR 15-MINUTE

EXPOSURE TO VAPORS OF VARIOUS FIRE EXTINGUISHING AGENTS<sup>a</sup>[Research by U.S. Army Chemical Center<sup>b</sup>]

Agent	Chemical formula	Halon no.	Approximate lethal concentration, ppm	
			Natural vapor	Decomposed vapor
Bromotrifluoromethane	$\text{CBrF}_3$	1301	800 000	<sup>c</sup> 14 000
Bromochlorodifluoromethane	$\text{CBrClF}_2$	1211	324 000	7 650
Carbon dioxide	$\text{CO}_2$	--	658 000	658 000
Dibromodifluoromethane	$\text{CBr}_2\text{F}_2$	1202	54 000	1 850
Chlorobromomethane	$\text{CH}_2\text{BrCl}$	1011	65 000	4 000
Carbon tetrachloride	$\text{CCl}_4$	104	28 000	300
Methyl bromide	$\text{CH}_3\text{Br}$	1001	5 900	9 600

<sup>a</sup>See reference 2.<sup>b</sup>Based on tests with white rats by the Medical Laboratories, U.S. Army Chemical Center.<sup>c</sup>Subsequent tests by Kettering Laboratory of the University of Cincinnati (unpublished data) with a commercial Halon 1301 of improved quality indicated that the lethal concentration of decomposed vapor is at least 20 000 ppm.

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TABLE III.- RELATIVE TOXICITY OF SOME COMMON HALIDE FIRE  
EXTINGUISHING AGENTS USING THE UNDERWRITERS'  
LABORATORIES, INC., GROUPINGS<sup>a</sup>

Agent	Chemical formula	Halon no.	Underwriters' Laboratories toxicity grouping
Bromotrifluoromethane	$\text{CBrF}_3$	1301	Group 6
Bromochlorodifluoromethane	$\text{CBrClF}_2$	1211	Group 5
Dibromotetrafluoroethane	$\text{C}_2\text{Br}_2\text{F}_4$	2402	Group 5 or 4
Dibromodifluoromethane	$\text{CBr}_2\text{F}_2$	1202	Group 4
Chlorobromomethane	$\text{CH}_2\text{BrCl}$	1011	Group 3
Carbon tetrachloride	$\text{CCl}_4$	104	Group 3

<sup>a</sup>See reference 2.

TABLE IV.- RELATIVE HAZARD IN USE<sup>a</sup>

Agent	Relative toxicity, volume basis		Relative efficiency as an extinguishing agent (b)	Relative toxicity hazard	
	Natural vapor	Decomposed vapor		Natural vapor	Decomposed vapor
Bromotrifluoromethane (Halon 1301)	1	1	1	$1 \times 1 = 1$	$1 \times 1 = 1$
Chlorobromomethane (Halon 1011)	12	3-1/2	4	$12 \times 4 = 48$	$3-1/2 \times 4 = 14$
Carbon tetrachloride (Halon 104)	29	47	5	$29 \times 5 = 145$	$47 \times 5 = 235$

<sup>a</sup>See reference 2.

<sup>b</sup>Computed from extinguisher fire tests conducted by E. I. DuPont de Nemours and Co., Inc., in a manner similar to Underwriters' Laboratories, Inc., testing procedures which indicate that 1 pound of bromotrifluoromethane has the extinguishing effect of 4 pounds of Halon 1011 and 5 pounds of Halon 104.

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TABLE V.- UNDERWRITERS' LABORATORIES CLASSIFICATION OF  
COMPARATIVE LIFE HAZARD OF FIRE EXTINGUISHING AGENT<sup>a</sup>

Group	Definition	Agent
6 (least toxic)	Gases or vapors which in concentrations up to at least about 20 percent by volume for durations of exposure of the order of 2 hours do not appear to produce injury.	FE-1301
5	Gases or vapors much less toxic than group 4 but more toxic than group 6.	Carbon dioxide
4	Gases or vapors which in concentrations of the order of 2 to 2-1/2 percent for durations of exposure of the order of 2 hours are lethal or produce serious injury.	Dibromodifluoromethane
3	Gases or vapors which in concentrations of the order of 2 to 2-1/2 percent for durations of exposure of the order of 1 hour are lethal or produce serious injury.	Bromochloromethane, carbon tetrachloride
2	Gases or vapors which in concentrations of the order of one-half to 1 percent for duration of exposure of the order of one-half hour are lethal or produce serious injury.	Methyl bromide

<sup>a</sup>See reference 3.

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TABLE VI.- CORRELATION OF U.S. ARMY CHEMICAL CENTER FINDINGS  
WITH UNDERWRITERS' LABORATORIES CLASSIFICATIONS<sup>a</sup>

Material	Chemical formula	Class	U.S. Army Chemical Center approximate lethal concentration, ppm by volume (b)	
			Undecomposed	Decomposed
FE-1301	CBrF <sub>3</sub>	6	832 000	<sup>c</sup> 14 000
Carbon dioxide	CO <sub>2</sub>	5a	657 000	--
Bromochloromethane	CH <sub>2</sub> BrCl	3	<sup>d</sup> 65 200	4 180
Carbon tetrachloride	CCl <sub>4</sub>	3	28 600	320
Carbon monoxide	CO	2	15 000	--
Methyl bromide	CH <sub>3</sub> Br	2	5 900	9 600

<sup>a</sup>See reference 3.

<sup>b</sup>Approximate lethal concentrations to rats for 15-minute exposure.

<sup>c</sup>Subsequent tests by Kettering Laboratory of the University of Cincinnati (unpublished data) with a commercial FE-1301 of improved quality indicated that the lethal concentration of decomposed vapor is at least 20 000 ppm.

<sup>d</sup>Another report (Ind. Hyg. and Occupational Med. 7 157, Feb. 1953) indicates that a concentration of 29 000 ppm is lethal to rats after 15-minute exposure.

TABLE VII.- COMBUSTION AND EXTINGUISHMENT TEST CONDITIONS AND RESULTS

Test number	Material	Flow rate	Flow time, sec	Total material	Elapsed time, sec	Reaction	Typical analyses of vapors above reaction tray, mol percent (a)									
							N <sub>2</sub>	O <sub>2</sub>	Ar	CO	CO <sub>2</sub>	H <sub>2</sub> H <sub>4</sub>	H <sub>2</sub> O	HF	FE-1301	FE-1301
1	FE-1301	20 lb/min	10	3.3 lb	10	None	61.0	13.0	0.5	Nil	Nil	Nil	0.5	Nil	Nil	25.0
2	H <sub>2</sub> O <sub>4</sub> FE-1301	0.3 cc/sec	10	3.0 cc	10	None	61.0	16.0	1.0	Nil	0.1	Nil	Nil	Nil	Nil	22.0
		20 lb/min	10	3.3 lb	20	None										
3	A-50 FE-1301	0.2 cc/sec	25	5.0 cc	25	None	61.0	16.0	0.6	Nil	0.1	2.0	0.4	Nil	Nil	20.0
		20 lb/min	10	3.3 lbs	35	None										
4	A-50 H <sub>2</sub> O <sub>4</sub>	0.2 cc/sec	35	7.0 cc	35	None	78.0	17.0	1.0	Nil	Trace	3.0	1.0	Nil	Nil	Nil
		0.3 cc/sec	5	1.5 cc	40	Flame										
5	A-50 H <sub>2</sub> O <sub>4</sub> FE-1301	0.2 cc/sec	40	8.0 cc	40	None	59.0	17.0	0.8	Nil	0.1	Trace	0.2	Nil	Nil	23.0
		0.3 cc/sec	10	3.0 cc	50	Flame										
		20 lb/min	10	3.3 lb	60	Flame out										
6	A-50 H <sub>2</sub> O <sub>4</sub> Nitrogen gas	0.2 cc/sec	35	7.0 cc	35	None	77.0	16.0	1.0	Nil	0.3	5.0	Nil	Nil	Nil	Nil
		0.3 cc/sec	5	1.5 cc	40	Flame										
		14 scfm	15	3.5 scf	55	No extinguishment										
7	Polyurethane sponge H <sub>2</sub> O <sub>4</sub> Hot wire	--	--	1 by 4 by 6 in.	--	None	81.0	16.0	1.0	Nil	Trace	Nil	1.5	Nil	Nil	Nil
		0.3 cc/sec	20	6.0 cc	20	None										
		--	--	--	35	Flame										
8	Polyurethane sponge H <sub>2</sub> O <sub>4</sub> Hot wire FE-1301	--	--	1 by 4 by 6 in.	--	None	68.0	12.0	0.8	Nil	Trace	Nil	0.5	Nil	Nil	19.0
		0.3 cc/sec	10	3.0 cc	10	None										
		--	--	--	25	Flame										
		20 lb/min	10	3.3 lb	35	Flame out										

<sup>a</sup>HBr, Br<sub>2</sub>, COF<sub>2</sub>, NO<sub>2</sub>, and F<sub>2</sub> were absent in all cases tested.

TABLE VII.- COMBUSTION AND EXTINGUISHMENT TEST CONDITIONS AND RESULTS - Concluded

Test number	Material	Flow rate	Flow time, sec	Total material	Elapsed time, sec	Reaction	Typical analyses of vapors above reaction tray, mol percent (a)							
							N <sub>2</sub>	O <sub>2</sub>	Ar	CO	CO <sub>2</sub>	H <sub>2</sub> H <sub>4</sub>	H <sub>2</sub> O	HF
9	Polyurethane sponge	--	--	1 by 4 by 6 in.		None								
	H <sub>2</sub> O <sub>4</sub>	0.3 cc/sec	20	6.0 cc	20	None								
	Hot wire	--	15	--	35	Flame	80.0	19.0	1.0	0.1	Trace	Trace	Nil	Nil
	Nitrogen gas	14 scfm	10	2.3 scf	45	No extinguishment								
10	Polyurethane sponge	--	--	1 by 4 by 6 in.		None								
	A-50	1.0 cc/sec	20	20 cc	20	None								
	FE-1301	20 lb/min	15	5 lb	35	None	60.0	14.0	1.0	Nil	0.1	3.0	2.0	Nil
	H <sub>2</sub> O <sub>4</sub>	0.3 cc/sec	22	6.6 cc	57	Flame								20.0
	FE-1301	20 lb/min	6	2.0 lb	63	Flame out								
11	A-50	1.0 cc/sec	57	57.0 cc	57	None								
	H <sub>2</sub> O <sub>4</sub>	2.0 cc/sec	47	94.0 cc	57	Flame								
	FE-1301	20 lb/min	22	7.3 lb	44	Flame out	43.0	10.0	0.6	7.0	0.1	Trace	Trace	Nil
	--	--	--	--	50	Flame								20.0
	FE-1301	20 lb/min	20	6.6 lb	84	Flame out								

<sup>a</sup>HBr, Br<sub>2</sub>, COF<sub>2</sub>, NO<sub>2</sub>, and F<sub>2</sub> were absent in all cases tested.

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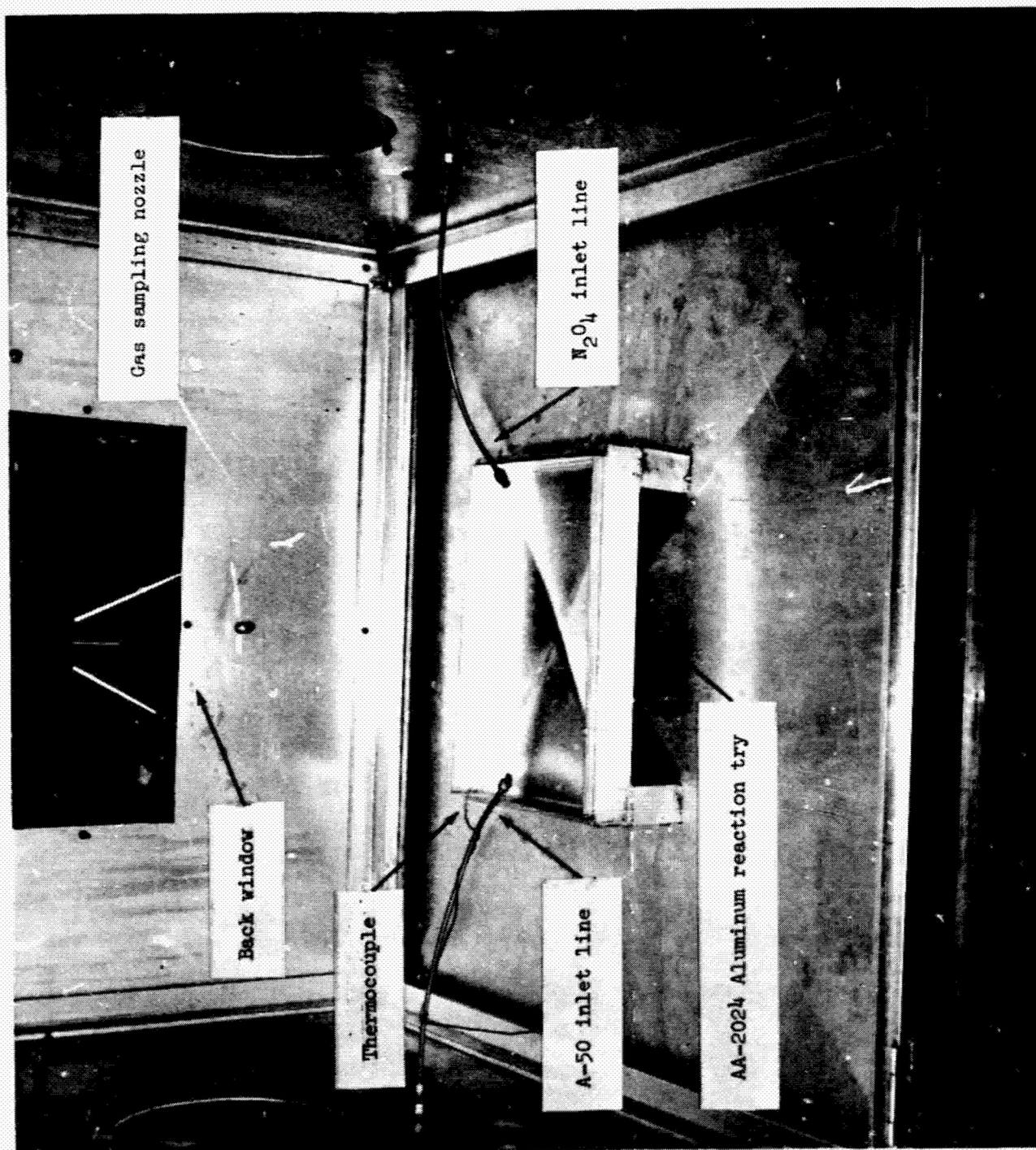


Figure 1.- Test cabinet, inside bottom.

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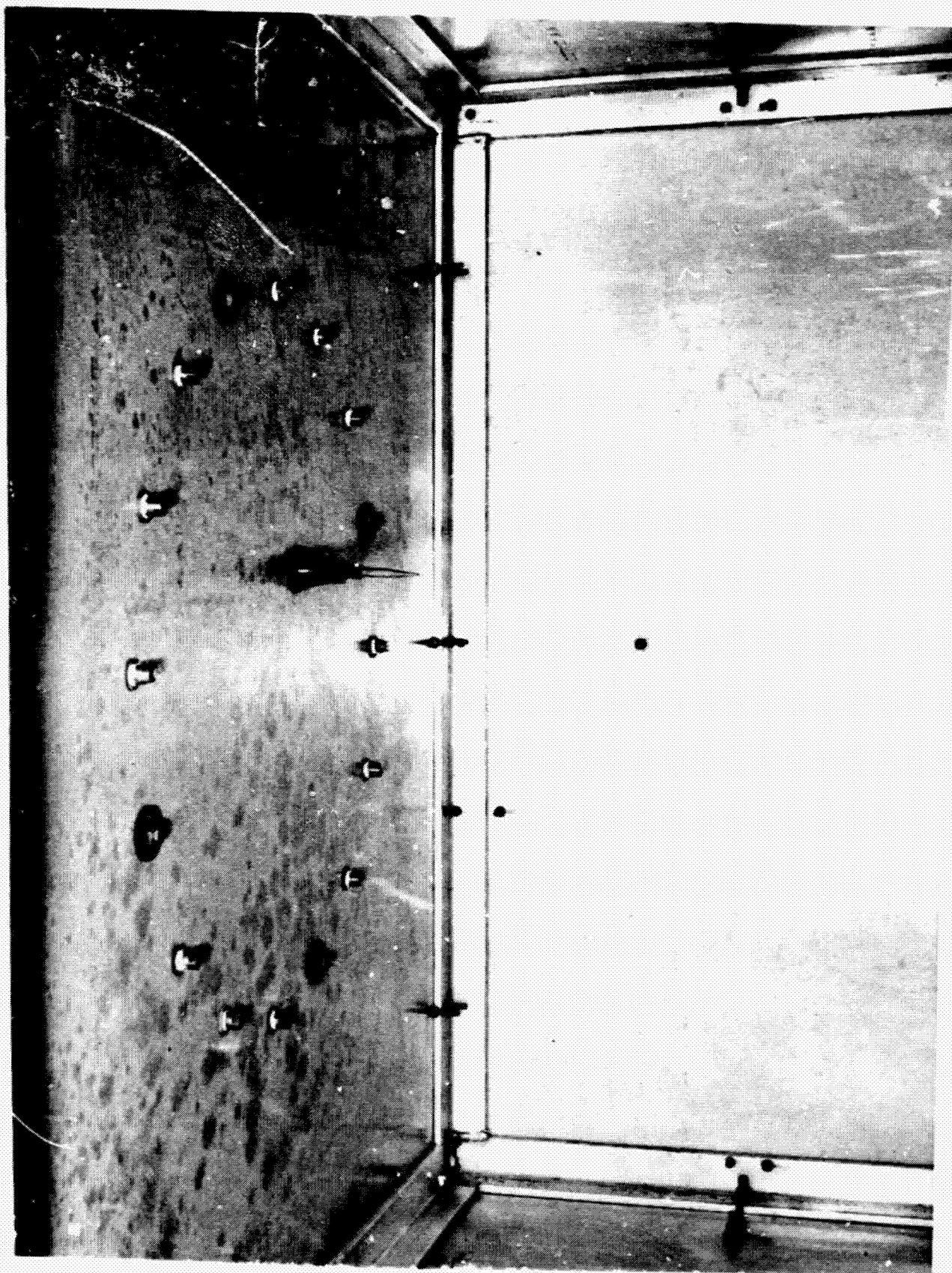


Figure 2.- Test cabinet, inside top, showing spray nozzles.

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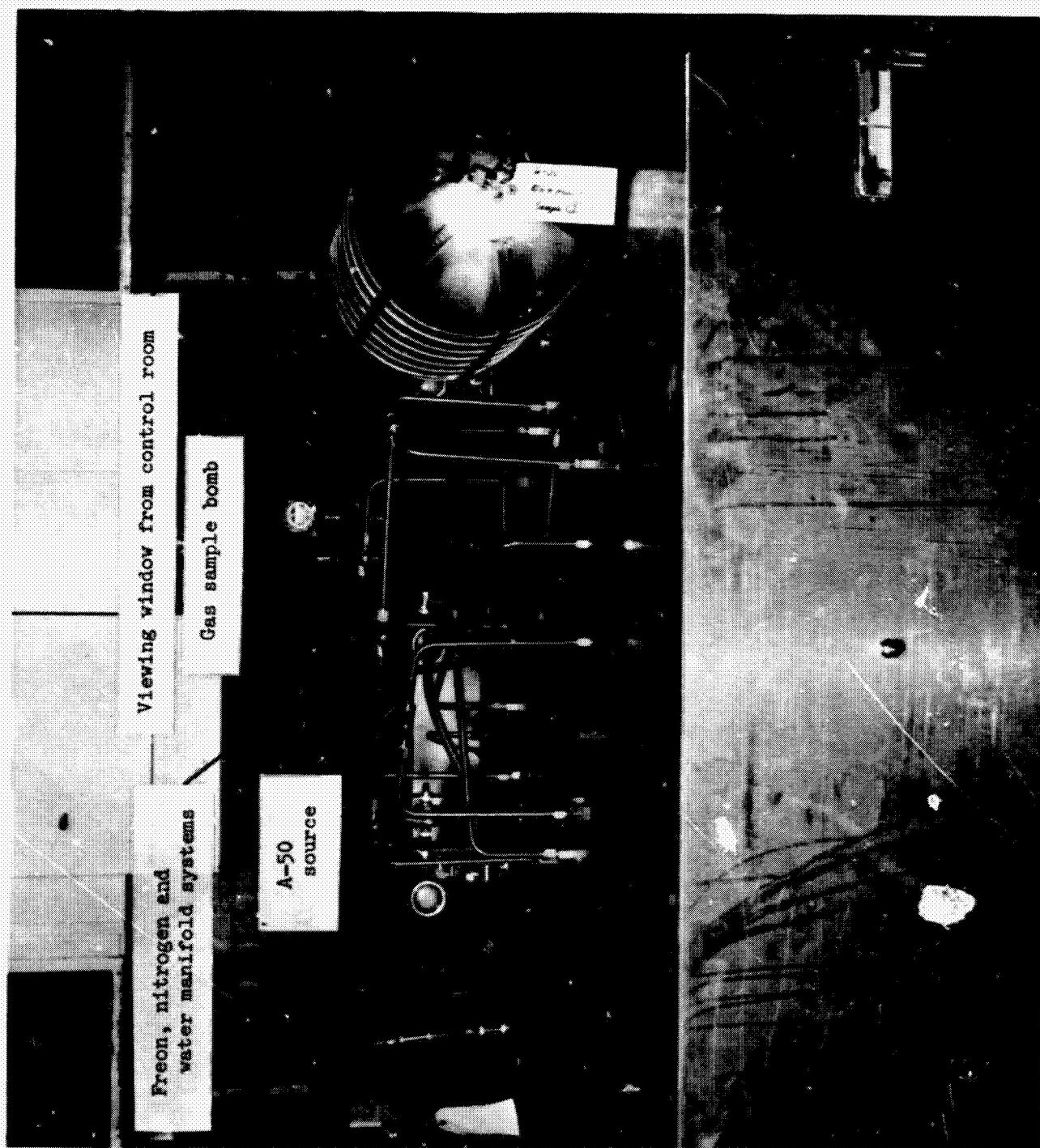


Figure 3.- Test cabinet, outside top, with door closed.

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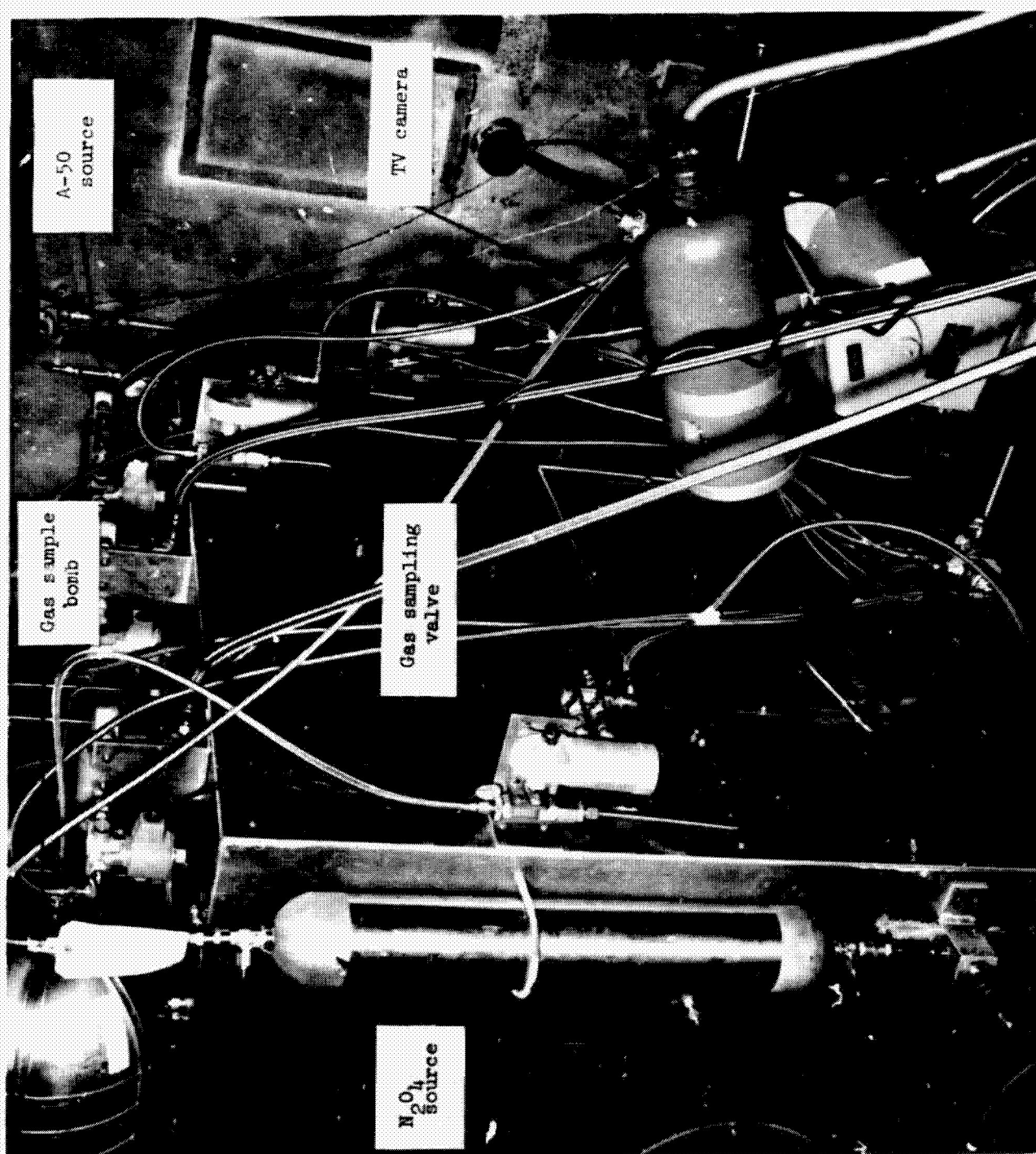


Figure 4.- Test cabinet, outside back.

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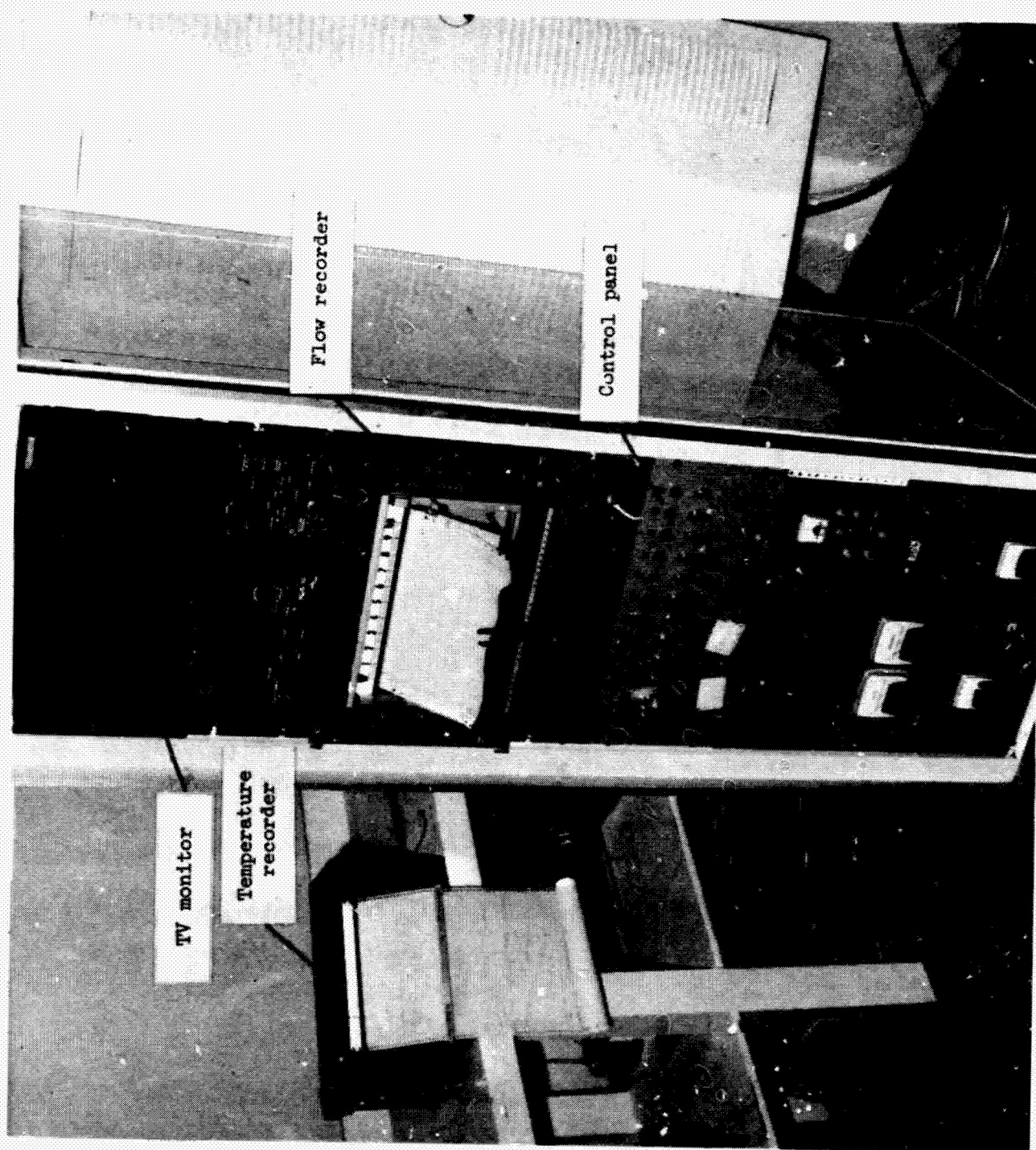


Figure 5.- Console for remote-control and data recording.

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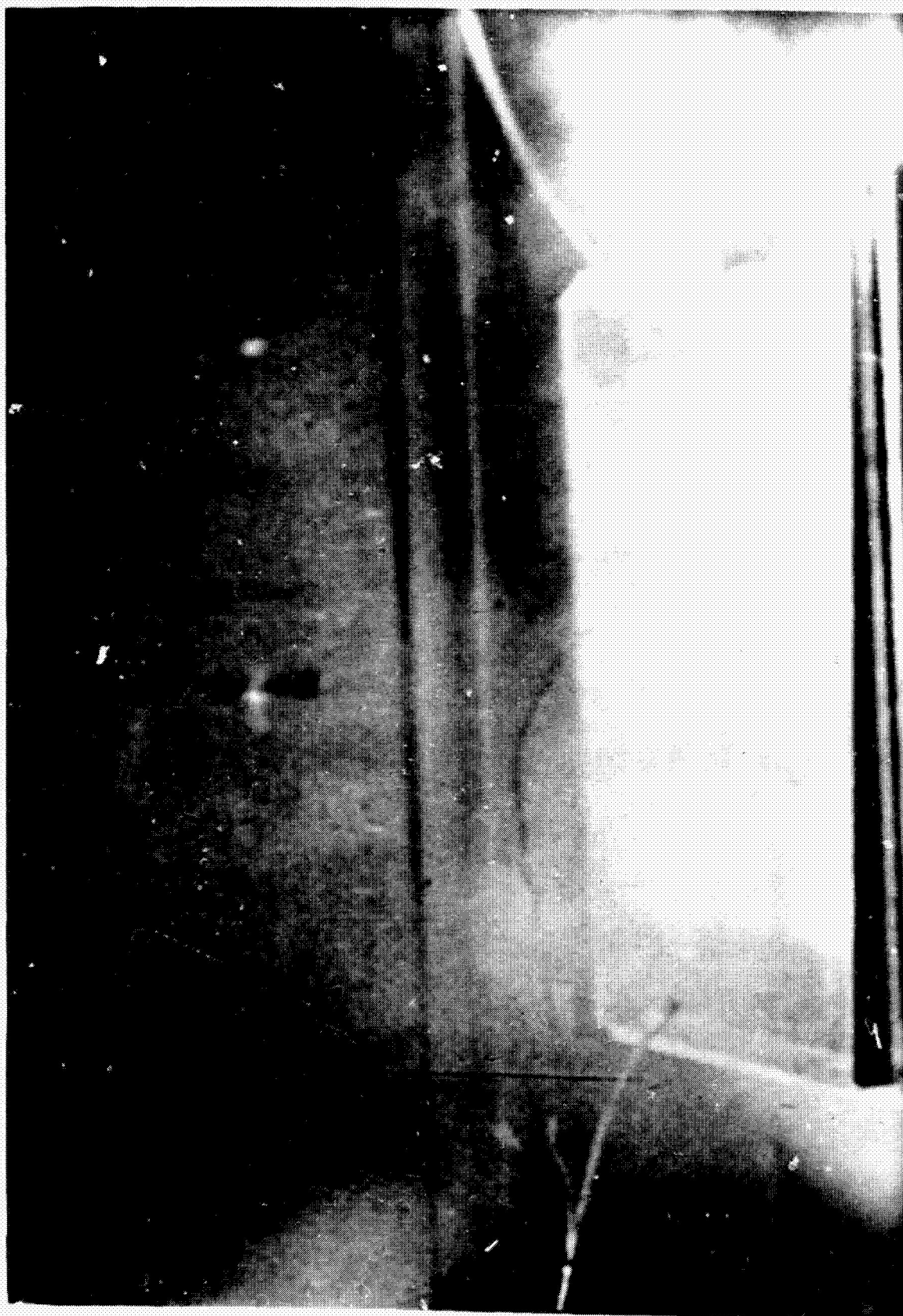


Figure 6.- Polyurethane saturated with A-50, being sprayed with Freon FE-1301.

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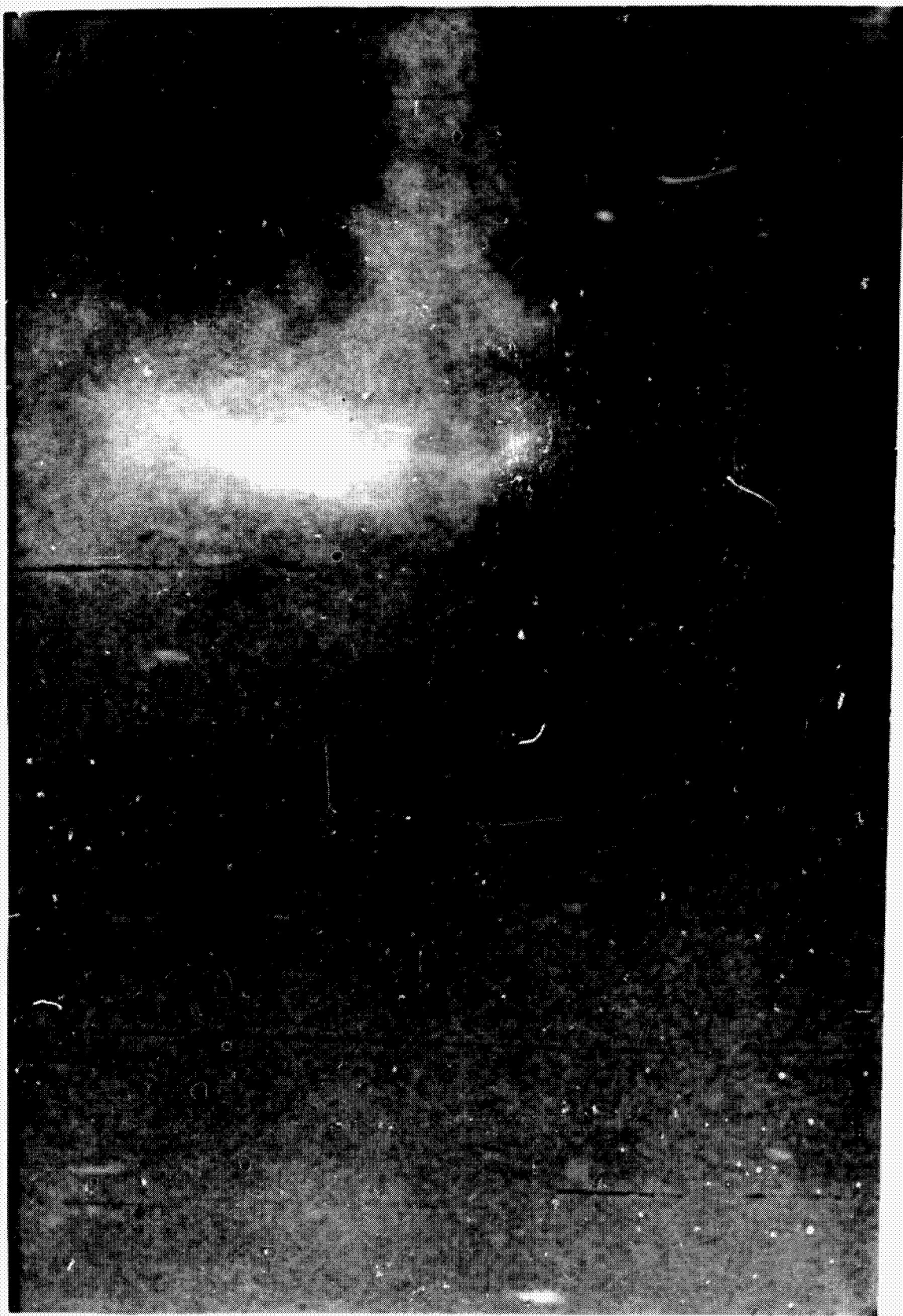


Figure 7.- Polyurethane saturated with A-50, being sprayed with Freon FE-1301 as  $N_2O_4$  is added.

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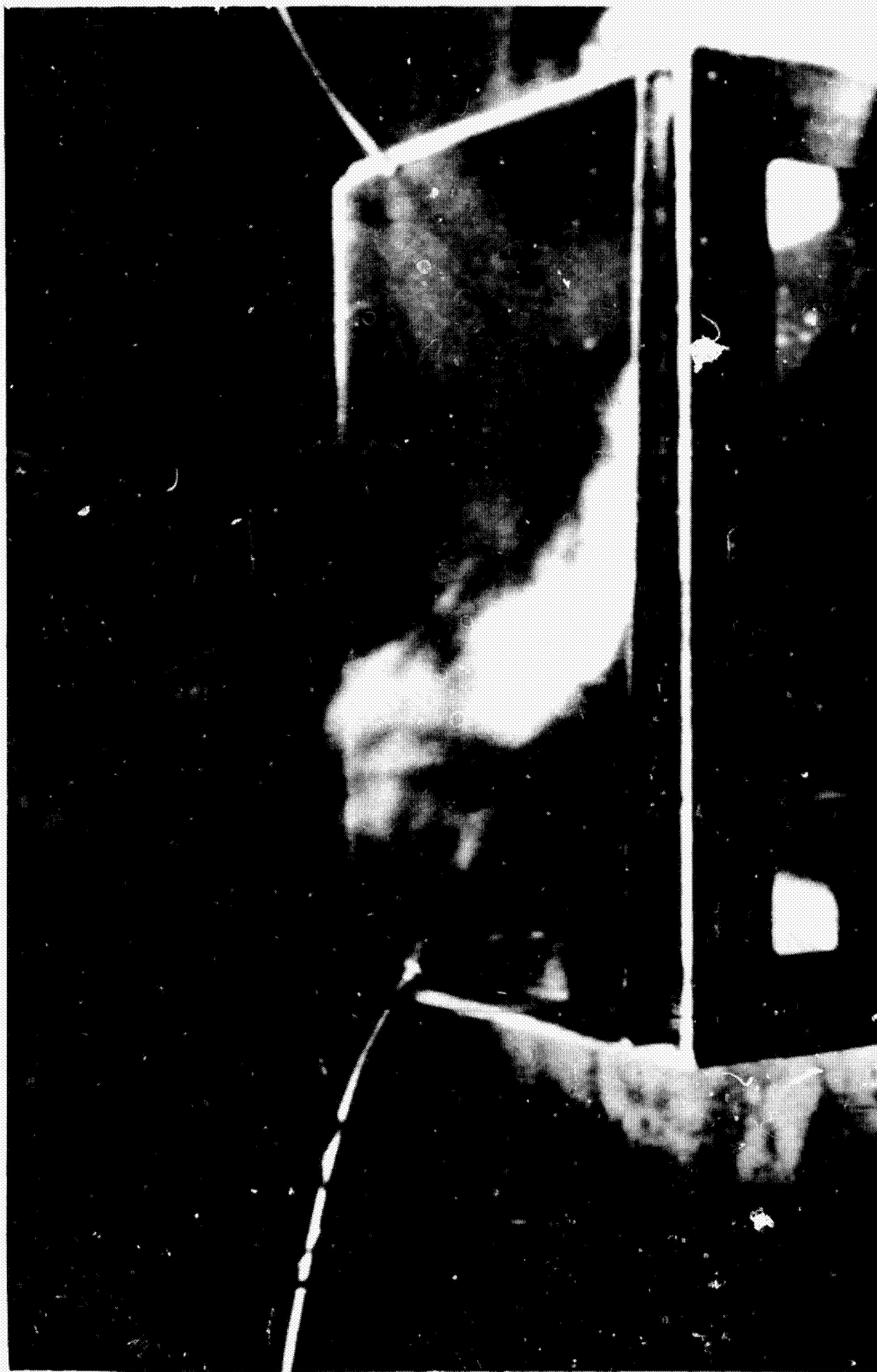


Figure 8.- Hypergolic fire produced by A-50 and  $N_2O_4$  propellants.

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Figure 9.- Hypergolic propellant fire after 10-second  
Freon FE-1301 spray.

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Figure 10.- Hypergolic propellant fire out after C2-second  
Freon FE-1301 spi J.

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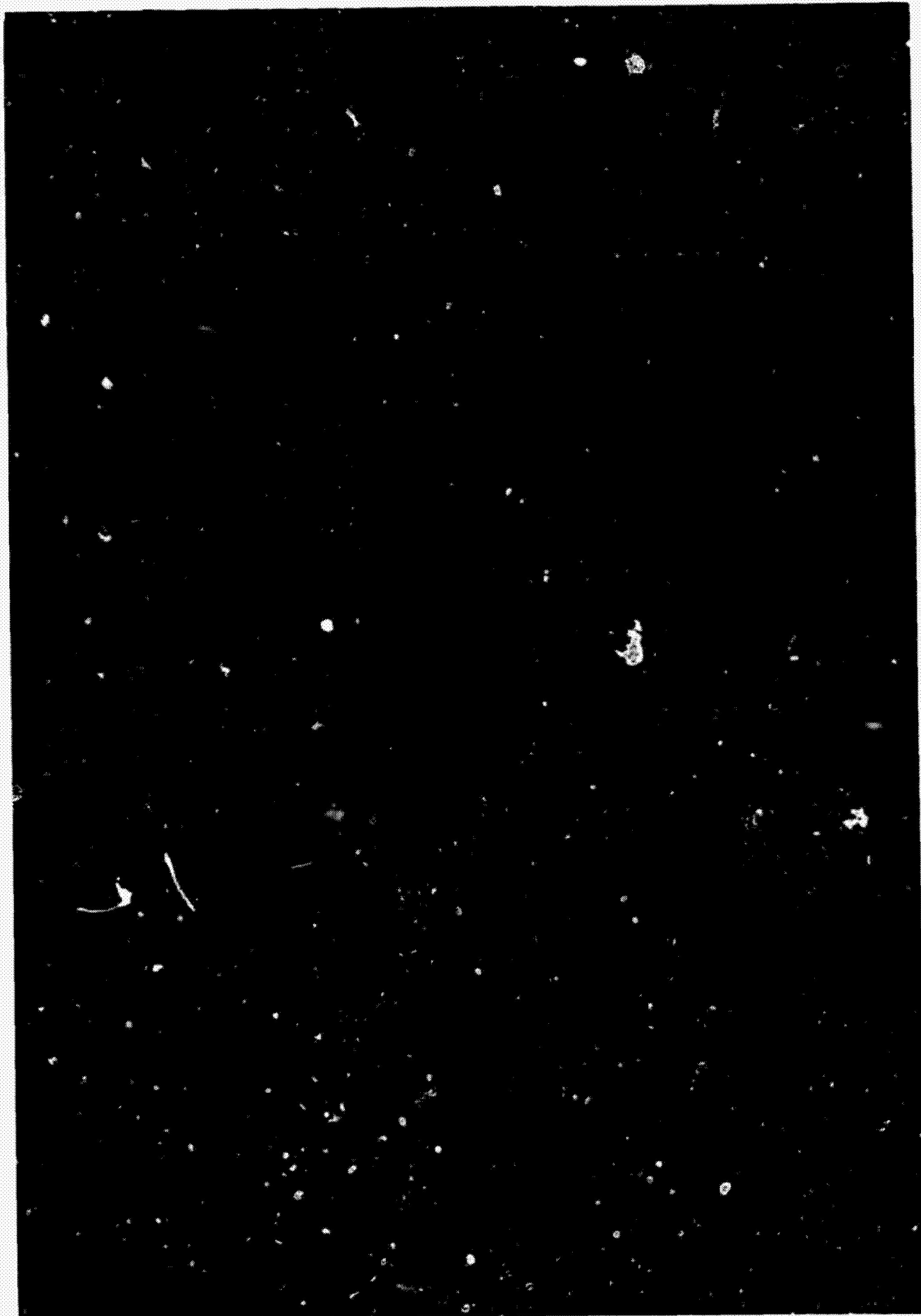


Figure 11.- Hypergolic propellant spontaneous flame immediately  
after Freon FE-1301 spray is discontinued.